Through Thick and Thin - Measuring Thickness in MRI

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Abstract Submission

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Introduction:

Thickness, especially cortical thickness, is a widely used metric in MRI, yet there is little in a gold standard to establish its veracity. Common methods (e.g. FreeSurfer) rely on complex procedures that generate surfaces and then compute thickness as a distance between nodes. Others rely on diffeomorphic mappings of nonlinear transformations (e.g. ANTs). Here, we present a suite of three novel, very fast volumetric thickness measurement tools. These are all based on simple image processing methods, implemented as scripts in the AFNI software package. The first two methods require only a mask of the object. The third takes two more masks for the "inside" and "outside" of the target.

Methods:

The methods rely on simple measurements of surrounding voxel neighborhoods to produce volumetric datasets that can be mapped onto a surface to show thickness. Here we tested three methods: Ball and Box, Erosion, and In-Out. Each of these methods were tested with
-synthetic models
-MRI data from human, macaque and marmoset brains
-Human studies with prior FreeSurfer metrics
-ABIDE database with prior thickness measurements
We also compared the thickness for the N27 dataset processed by FreeSurfer.

Ball and box
This method defines depth as the size of the largest sphere or cube that will fit around a voxel, while staying entirely within the mask. Using cubes extends depth measures into corners more readily. An additional dataset is produced by mapping spheres of the depth of each voxel from smallest to largest, each at least partially encompassing its predecessor. The thickness is then defined volumetrically as the largest depth sphere, often from a neighboring voxel, that contains each given voxel.

Erosion
This method finds thickness by the proxy of levels of an iterative simple morphological erosion, the process of removing voxels that are at the edge of the mask. With each iteration, more voxels are eroded from the mask until none remain. Like the first method, this method also produces a depth measure that can be converted to thickness either volumetrically or to a surface.

In-Out
Like the ball and box method above, this method also grows spheres in local neighborhoods around each voxel but instead looks for the minimum sphere that reaches the inside mask and another size sphere to reach the outside mask. The radii of these two spheres represent distances to the inside and outside masks. The thickness is defined as simply the sum of these two distances.

Testing:
Synthetic models. Because thickness standards do not exist for brains, each method was validated with models of simple shapes of predetermined sizes on voxel grids of 0.5mm3. For the first two methods, simple cylinders and rectangular blocks were generated at 1mm increments over a range of 2-8mm. For the In-Out methods, these models were extended with interior and exterior concentric volumes, and the target volume to be an annular cylinder or hollow box.

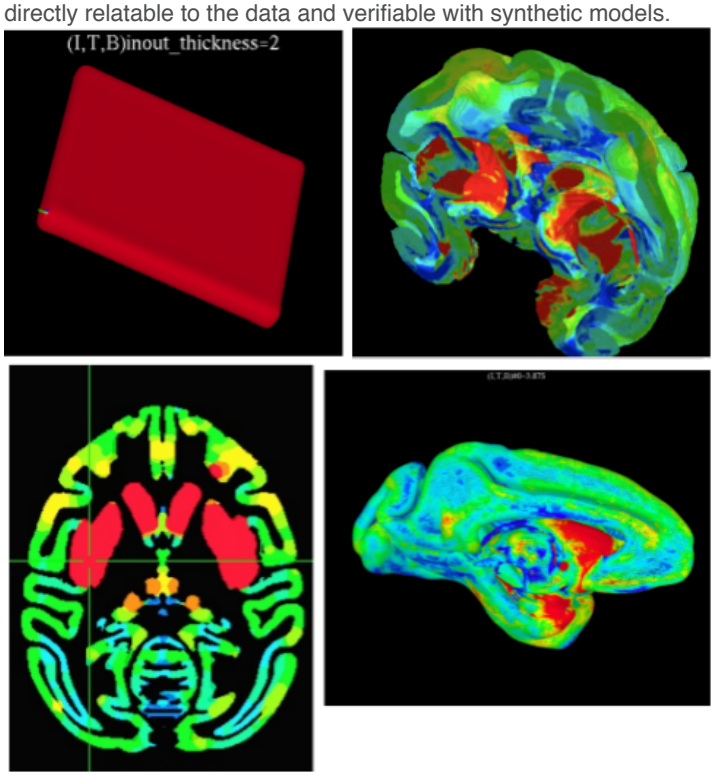
Results:

Synthetic models:
Each method produced essentially exact results at most locations except corners.

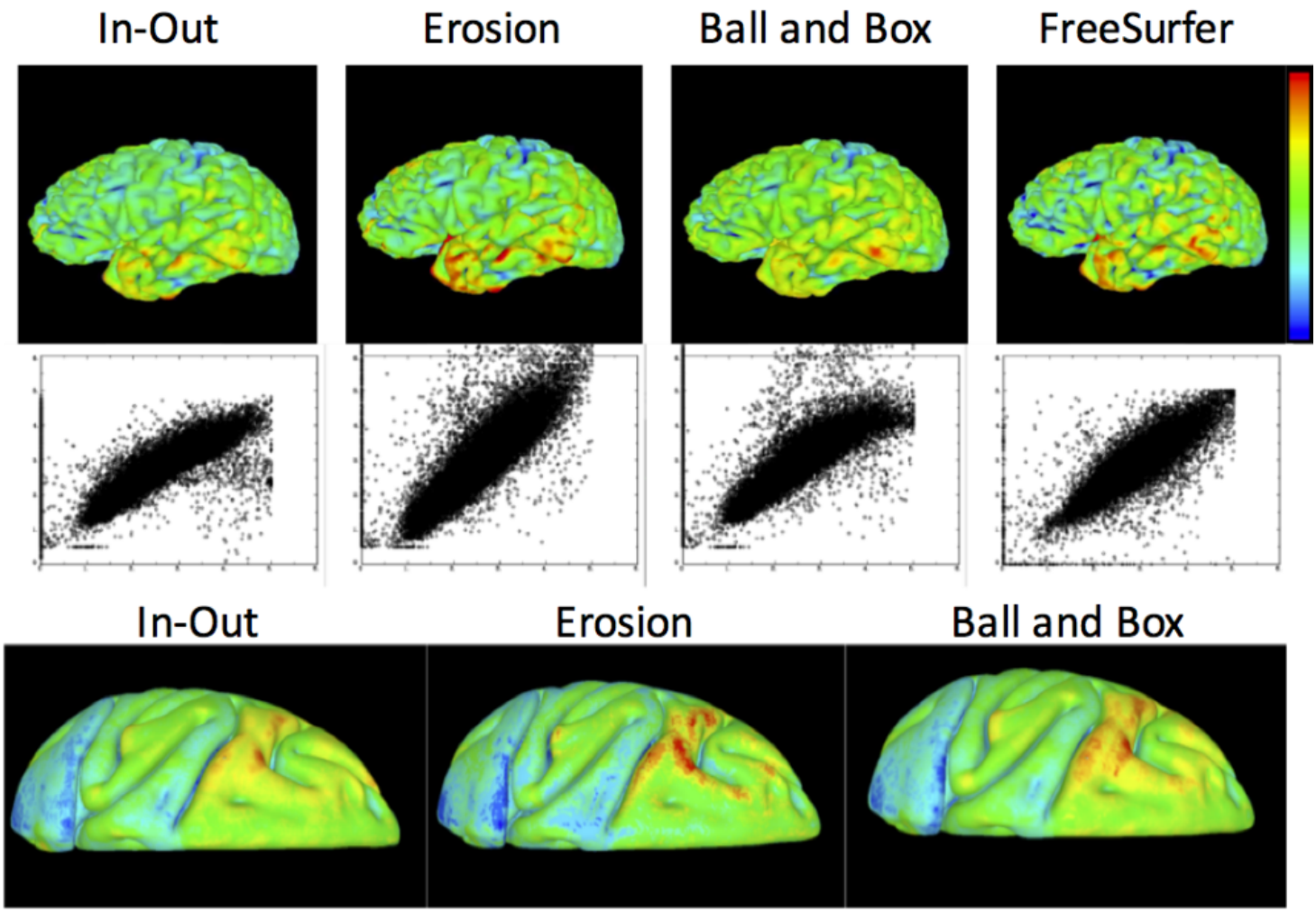
For both macaque and marmoset, the methods gave reasonable thickness maps with values ranging from 1-5mm. For human data, thickness maps from the morning/evening scans were highly comparable and correlated to those produced by FreeSurfer (r=0.69,0.72,0.79 across subjects for Ballbox,Erosion,In-Out,respectively).

Conclusions:

Thickness has several meanings, and all methods provide different interpretations. It can mean distance from in to out, the size of ball that can fit inside the object, deformation distance, shortest distance between sheets,…. Each software provides a metric based on its own algorithm. Here we provide a set of simple programs and metrics that can be used on a variety of objects including brain cortex, but also any other mask, such as lesions and regions. The methods are applicable to animal studies too with the advantage of simplicity, speed - directly relatable to the data and verifiable with synthetic models.



·Thickness examples. Synthetic model, NMT macaque template cut-away view, thickness volume, medial surface view (colors correspond to 1-4mm)



·Single subject FreeSurfer Thickness Comparisons, (smoothed to 8mm,Colors 2-5 or 6mm), Corresponding scatterplots and FreeSurfer Day2 vs FreeSurfer Day 1 on x-axis. NMT Macaque thickness (unsmoothed)

Imaging Methods:

Anatomical MRI [2]
Imaging Methods Other

Informatics:

Brain Atlases
Informatics Other

Modeling and Analysis Methods:

Methods Development [1]

Keywords:

Cortex
Structures
Sub-Cortical
Other - thickness

[1|2]Indicates the priority used for review

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Yes

Please indicate which methods were used in your research:

Structural MRI

For human MRI, what field strength scanner do you use?

3.0T
7T

Which processing packages did you use for your study?

AFNI
Free Surfer

Provide references using author date format

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Das SR (2009), Registration based cortical thickness measurement. Neuroimage, 45(3):867–879.
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